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The Performance of HIPERLAN/2 Systems with Multiple Antennas

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Abstract

This paper investigates the performance of the ETSI HIPERLAN/2 standard with dual antenna diversity utilized at mobile terminals. Software-simulated physical layer Packet Error Rate (PER) results are presented for both transmit (up-link) and receive (down-link) diversity configurations. The impact of the improved physical layer performance that results from the use of multiple antennas is discussed in terms of increased throughput on the down-link and reduced transmit power on the up-link.

1. Introduction

HIPERLAN/2 [1], defined by ETSI BRAN (European Telecommunications Standardization Institute Broadband Radio Access Networks), is a Wireless Local Area Network (WLAN) operating in the 5 GHz band. It is designed to provide high-speed communication, at up to 54 Mbit/s, between portable devices and various fixed core broadband networks. The system supports two basic modes of operation: centralized mode and direct mode. In centralized mode, HIPERLAN/2 provides a cellular wireless access network to the core infrastructure via fixed access points (APs). Each AP covers a certain geographical area and can serve a number of mobile terminals (MTs) attached to it.

Multiple or multi-beam antennas at the AP are supported by the HIPERLAN/2 standard in order to provide improved link quality and, when directional antennas are used, to reduce the interference introduced into the radio network. In this paper, the use of multiple antennas within this framework is not considered. Instead, *the additional benefits of the improved radio link that results from deploying two antennas at MTs are assessed.*

Results from a HIPERLAN/2 physical layer software simulation are used to analyze the various performance improvements that can be obtained. In the down-link (DL) case, diversity reception techniques are examined.

For the up-link (UL), because HIPERLAN/2 operates with a Time Division Duplex (TDD) medium access mechanism, Channel State Information (CSI) from the DL can be used to control UL transmissions across the two antennas. The enhanced link performance that this yields is examined. In addition, recognizing that the effectiveness of the technique is ultimately bound by the validity of the DL CSI at the time of UL transmission, the limiting effects of Additive Gaussian White Noise (AWGN) and channel time variance are studied.

The paper is organized as follows: Section 2 provides a brief outline of the HIPERLAN/2 standard. Section 3 then compares the performance of a number of diversity combination approaches. Section 4 outlines several transmit diversity techniques. In addition to the performance gains that they can yield, the limitations of the techniques are discussed. Finally, in Section 5 some implications of the results are discussed further.

2. The HIPERLAN/2 Standard

The HIPERLAN/2 standard is split into three layers: the Data Link Control (DLC) and Physical (PHY) layers, which are core network independent, and a set of Convergence Layers (CLs), which are network-specific. The technical specifications define a radio access network that is able to operate at rates up to 54 Mbit/s, provides support for multimedia Quality of Service (QoS) parameters and, through the various CLs, can flexibly interconnect with various wired core networks.

The Medium Access Control (MAC) protocol, which is part of the DLC layer, uses a Time Division Multiple Access (TDMA) Time Division Duplex (TDD) approach. A centralized scheduling algorithm, implemented in the AP, controls the medium access, determining how the data transmission resources provided by the PHY layer are shared between MTs connected to the AP. The MAC mechanism is based around 2 ms frames, within which time slots are assigned for broadcast, DL and UL payload, and resource request transmissions. Preambles are transmitted regularly in order to allow accurate CSI estimation.

The HIPERLAN/2 PHY layer is based on Orthogonal Frequency Division Multiplexing (OFDM) transmission. Convolutional coding is employed across OFDM subcarriers in order to combat the effects of frequency selective fading. Each OFDM symbol comprises 48 data-bearing and 4 pilot subcarriers, and modulation and demodulation can be implemented by means of a 64-point Fast Fourier Transform (FFT) operation. Several modulation modes, each with different modulation and forward error correction configurations are specified. These allow the system to vary transmission rate depending on the channel conditions. Table 1 outlines these modes. *Link adaptation*, or the selection of a transmission mode suitable for the transmission characteristics, is part of the radio network functionality of the DLC. The transmission mode in either direction (UL or DL) is a function of the perceived radio link quality.

Table 1. PHY layer modes

Mode	Modulation	Coding Rate R	Bit rate [Mbit/s]
1	BPSK	1/2	6
2	BPSK	3/4	9
3	QPSK	1/2	12
4	QPSK	3/4	18
5	16QAM	9/16	27
6	16QAM	3/4	36
7	64QAM	3/4	54

3. Receive Diversity (down-link)

Figure 1 illustrates a dual antenna diversity receiver configuration. The signals received on each antenna (labeled antenna A and antenna B) are demodulated separately. It is assumed that the demodulation processing includes time and frequency synchronization, and formation of the CSI for each channel, $H_{A,k}$ and $H_{B,k}$. The received data vectors from the antennas, $R_{A,k}$ and $R_{B,k}$, are then merged into one stream R_k , according to the diversity combination algorithm being used, and Viterbi decoding is performed on the resulting stream.

In this section, the deployment of diversity reception at a HIPERLAN/2 MT is considered. The improved-quality radio link that results from the use of diversity is demonstrated. It is proposed that the key benefit of this arrangement on a HIPERLAN/2 system is increased down-link throughput for a given link budget.

Three diversity combination algorithms are considered:

1. Antenna Selection

The signal from the antenna with the highest average received power is selected; i.e. R_k is either $R_{A,k}$ or $R_{B,k}$ for all k , dependent on which is greater: the sum

of $|H_{A,k}|^2$, or the sum of $|H_{B,k}|^2$. It would be straightforward to implement this type of selection based on a Received Signal Strength Indicator (RSSI) for the two antennas. This approach would also preclude the need for full demodulation of the two streams.

2. Subcarrier Selection

The subcarrier with the highest magnitude response across the two antennas is selected; i.e. for any k , R_k is either $R_{A,k}$ or $R_{B,k}$ dependent on which is greater: $H_{A,k}$ or $H_{B,k}$.

3. Maximal Ratio Combining

The subcarriers are phase-aligned and weighted by their power. This is achieved by multiplying each received vector by the conjugate of the appropriate channel response; i.e. $R_k = R_{A,k}(H_{A,k})^* + R_{B,k}(H_{B,k})^*$, for all k .

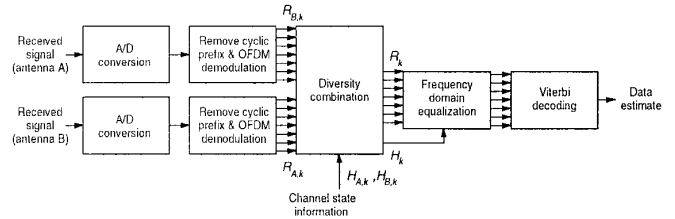


Figure 1. Dual antenna diversity receiver configuration (MT receiver)

Note that, in each case, the CSI passed on for subsequent frequency domain equalization, H_k , is the appropriate combination of the CSIs for the two antennas, $H_{A,k}$ and $H_{B,k}$.

Figure 2 shows the Packet Error Rate (PER) performance of mode 3 of the HIPERLAN/2 PHY layer with these diversity combination techniques. The result when one antenna only (no diversity) is used is also shown. PER is plotted against C/N_0 , the ratio of the average received subcarrier power to the average power of the Additive White Gaussian Noise (AWGN) at the receiver. The results are based on ETSI BRAN HIPERLAN/2 channel model 'A' [2]. This represents a 'typical office environment for non line of sight conditions and 50 ns average rms delay spread'. The same average fading profile was assumed for each antenna, although the channel impulse response taps were subject to independent and uncorrelated Rayleigh fading. The results are based on the assumption that the MT uses a hard-decision Viterbi decoder [3].

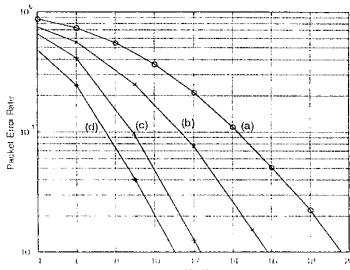


Figure 2. PER performance of HIPERLAN/2 mode 3 with dual antenna receive diversity techniques: (a) No diversity; (b) Antenna selection; (c) Subcarrier selection; (d) Maximal ratio combining

Figure 3 summarizes results for all HIPERLAN/2 modes. This figure shows the value of C/N_0 required to achieve a PER of 10^{-2} without diversity and with each of the three diversity configurations.

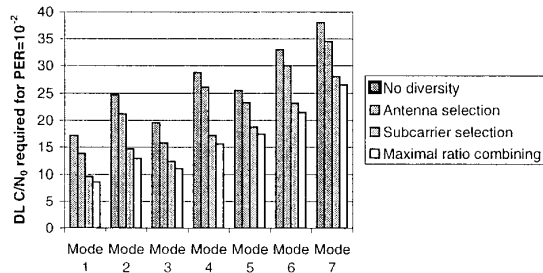


Figure 3. DL C/N_0 required to achieve a PER of 10^{-2} for HIPERLAN/2 modes with dual antenna receive diversity techniques

From the above results, it can be seen that the performance with diversity is substantially better than without. The gain with antenna selection diversity over a system without diversity is found to be between 2 and 4 dB. Subcarrier selection yields a further gain of between 3 and 9 dB, and the benefit of maximal ratio combining over this is between 1 and 2 dB.

In terms of the HIPERLAN/2 network, the diversity reception techniques can lead to a significant increase in DL throughput given a fixed link budget. The diversity gain versus added complexity must, of course, be traded off. Nevertheless, the implementation of diversity effectively causes an improvement in the average quality of the radio link and, as a result, the link adaptation algorithm can select higher modes more frequently.

For example, given that an AP transmits with power sufficient to provide $C/N_0=25$ dB at the receiver, the results in Figure 3 indicate that with no diversity the DL is, on average, restricted to operation in mode 3 (12

Mbit/s) in order to meet the target PER of 10^{-2} . However, with subcarrier selection or maximal ratio combining, the average DL mode of operation is mode 6 (36 Mbit/s). The improved link quality and corresponding increases in throughput should be seen as a major benefit for a WLAN system like HIPERLAN/2. The increased use of high-rate modulation modes on the DL implies either that higher rate services can be supplied to a given MT, or that more MTs can be supported by an AP.

4. Transmit Diversity (up-link)

Figure 4 illustrates a dual antenna diversity transmitter configuration. As in the receiver diversity case, there are two signal streams. These are modulated and transmitted separately. A diversity weighting algorithm defines how the signals are split across the two antennas. It is assumed that the two antennas are placed at the MT. The splitting algorithm is therefore based on the CSI that resulted from the most recent DL transmission from the AP.

In this section, the impact of transmit diversity at the MT on the quality of UL transmission is examined. The technique is shown to be limited by the fact that the DL CSI is inaccurate at the time of UL. Again, results are presented for hard-decision Viterbi decoding (this time at the AP). However, the effects of a more complex decoding strategy at the AP are also considered.

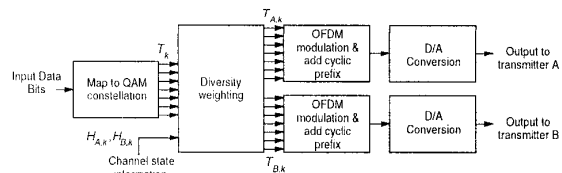


Figure 4. Dual antenna diversity transmitter configuration (MT transmitter)

Three diversity weighting algorithms are considered:

1. **Antenna Selection**
The antenna that received the highest average power on the previous DL transmission is selected; i.e. either $T_{A,k}=T_k$ and $T_{B,k}=0$ for all k , or $T_{B,k}=T_k$ and $T_{A,k}=0$ for all k , dependent on which is greater: the sum of $|H_{A,k}|^2$, or the sum of $|H_{B,k}|^2$. This is essentially the reciprocal arrangement to receive diversity with antenna selection.
2. **Subcarrier Selection**
The subcarrier with the highest magnitude response across the two antennas on the previous DL transmission is selected; i.e. for any k , T_k is either

$T_{A,k}$ or $T_{B,k}$, dependent on which is greater: $H_{A,k}$ or $H_{B,k}$. This is the reverse arrangement to receive diversity with subcarrier selection.

3. Phase Alignment

The subcarriers are rotated so that they align at the receiver and a half-power signal is transmitted on each antenna; i.e. $T_{A,k} = T_k(H_{A,k})^* / (|H_{A,k}| \sqrt{2})$ and $T_{B,k} = T_k(H_{B,k})^* / (|H_{B,k}| \sqrt{2})$ for all k .

The TDD nature of the HIPERLAN/2 MAC is of fundamental importance to these transmit diversity techniques; because the UL and DL share the same frequency spectrum, we assume that the nature of the physical channel is the same for both UL and DL transmissions. Of course, this will not strictly be the case, and knowledge of the CSI from DL transmissions will, at the time of UL, be inaccurate. The two key mechanisms that will corrupt the CSI are AWGN at the MT receiver, and channel time variance. Figure 5 shows the performance of the transmit diversity techniques for mode 3 when the CSI is corrupted with AWGN on the DL, but the channel is static. Figure 6 shows the UL performance when the channel is time variant, but the CSI is free of AWGN.

Channel time variance was modelled with a classical Jake's Doppler spectrum corresponding to a terminal speed of 3 m/s on each tap of the channel impulse response. This corresponds to the maximum Doppler rate $v = v/\lambda = 3/0.056 = 53.5$ Hz at 5350 MHz, which is the highest frequency in the band designated for indoor operation of HIPERLAN/2. Note that this rate is "worst case" and much higher than measurements in typical office environments indicate. In [4], for example, the average coherence time of an indoor channel was found to be 250 ms.

From Figures 5 and 6, it can be seen that the transmit diversity techniques are more sensitive to channel time variance than to AWGN on the CSI. With a delay of 6 ms between DL and UL transmissions, the performance improvement with antenna selection diversity falls from more than 3 dB to less than 1 dB. Similarly, the improvement observed with subcarrier selection, and with maximal ratio combining fall by greater than 5dB. Nevertheless, given the MAC frame duration of 2 ms and assuming regular UL and DL transmission, we conclude that the performance improvements that transmit diversity can yield are still significant. Moreover, we reiterate that measurements at 5.2 GHz have shown that the coherence time of indoor channels is typically many times the HIPERLAN/2 MAC frame duration [4].

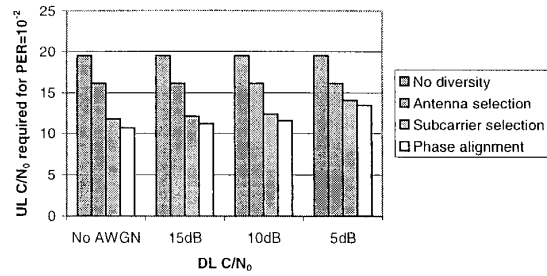


Figure 5. UL C/N_0 required to achieve a PER of 10^{-2} for HIPERLAN/2 mode 3 with dual antenna diversity transmission techniques. The CSI is corrupted due to AWGN on the DL.

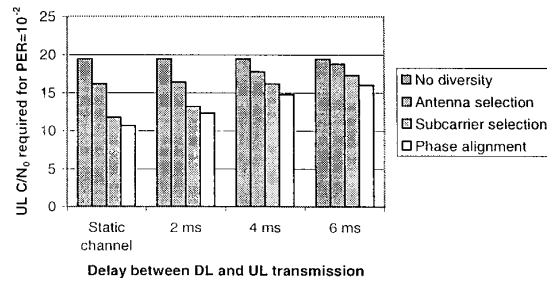


Figure 6. UL C/N_0 required to achieve a PER of 10^{-2} for HIPERLAN/2 mode 3 with dual antenna diversity transmission techniques. The CSI is corrupted due to delay between DL and UL transmission.

Figure 7 shows the performance of the transmit diversity techniques (with hard decision Viterbi decoding at the AP) for all HIPERLAN/2 modes with a delay of 2 ms between UL and DL, and average DL $C/N_0=10$ dB.

Again, the improved link that results from the use of diversity is significant. The enhanced UL that results from diversity transmission can lead to significant power savings at the MT. This is an important issue for battery-powered portable units. With two antennas at the MT, in order to achieve reliable UL communication in a given mode, the required RF transmit power is substantially reduced. For example, for operation in mode 3 the UL transmit power required to achieve an average PER of 10^{-2} with diversity by phase alignment is more than 6 dB lower than with only a single antenna at the MT. This reduces the peak power output at the MT, thus easing PA design and reducing losses due to linear PA inefficiency. With subcarrier selection and phase alignment, there is also a further 3 dB reduction in the average output power per PA, because the output OFDM signals are split between two transmit streams.

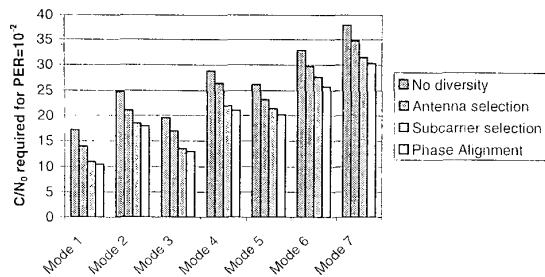


Figure 7. UL C/N_0 required to achieve a PER of 10^{-2} for HIPERLAN/2 modes with dual antenna diversity transmission techniques and hard decision Viterbi decoding at the AP. The CSI is corrupted due to a 2 ms delay between DL and UL transmission and 10 dB average C/N_0 on the DL.

Figure 8 shows similar results to those of Figure 7, but with soft decision Viterbi decoding with branch metrics weighted by the CSI [3] implemented at the AP. The results in Figure 8 confirm that, even with an enhanced decoding strategy implemented at the AP, the benefits of diversity transmission are maintained.

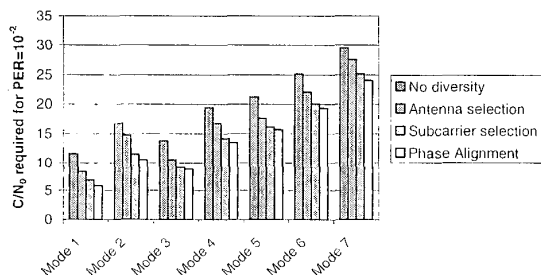


Figure 8. Equivalent results to Figure 7, but with soft decision Viterbi decoding with the branch metrics weighted by the CSI at the AP.

5. Discussion

The results above indicate that the implementation of diversity techniques within HIPERLAN/2 MTs can yield significant performance improvements. With diversity reception, for a given link budget the average DL throughput can be substantially enhanced by the more frequent use of higher modulation modes. In the case of diversity transmission for the UL, results indicate a maximum reduction in transmit power of greater than 8 dB.

In a practical sense, it is important to note that it is possible to include two MT antennas at 5 GHz with sufficiently low correlation over the subcarriers.

Typically an antenna spacing of $\lambda/2$ (i.e. 2.5-3 cm) gives a correlation lower than 0.5. Furthermore, it has been shown in [5] that the signals are close to iid for an antenna separation of one wavelength.

Another important issue, not considered here, is how the deployment of sectorized antennas at the AP will affect the enhanced performance due to diversity at the MT. As mentioned previously, the use of multiple AP antennas is supported within the HIPERLAN/2 standard, and gains of more than 13 dB have been reported using 60° sectorized antennas at the AP [6]. In this paper, we have, in effect, assumed an omni-directional antenna at the AP, and it is unclear what effect factors such as reduced multipath and more Rician channel fading statistics will have on the results. This is an issue that requires further attention.

The diversity strategies discussed here demand a more complex hardware architecture than systems using a single antenna. The most effective diversity structures incorporate two RF-baseband chains and FFT processes, as well as suitable hardware to implement the diversity combination. The key issue that will determine whether or not the deployment of multiple antennas at HIPERLAN/2 mobile terminals is of practical use is whether or not the benefits that they yield outweigh the increased cost of the MT.

Acknowledgements

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